Howard Schroeder

PREPARED FOR THE USE OF DEPARTMENT
OF WATER RESOURCES, STATE OF CALIFORNIA

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

# HYDRAULIC MODEL STUDIES OF THE PRESSURE-RELIEF PANELS IN THE POWERPLANT INTAKE STRUCTURE--OROVILLE DAM--CALIFORNIA

CALIFORNIA DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA

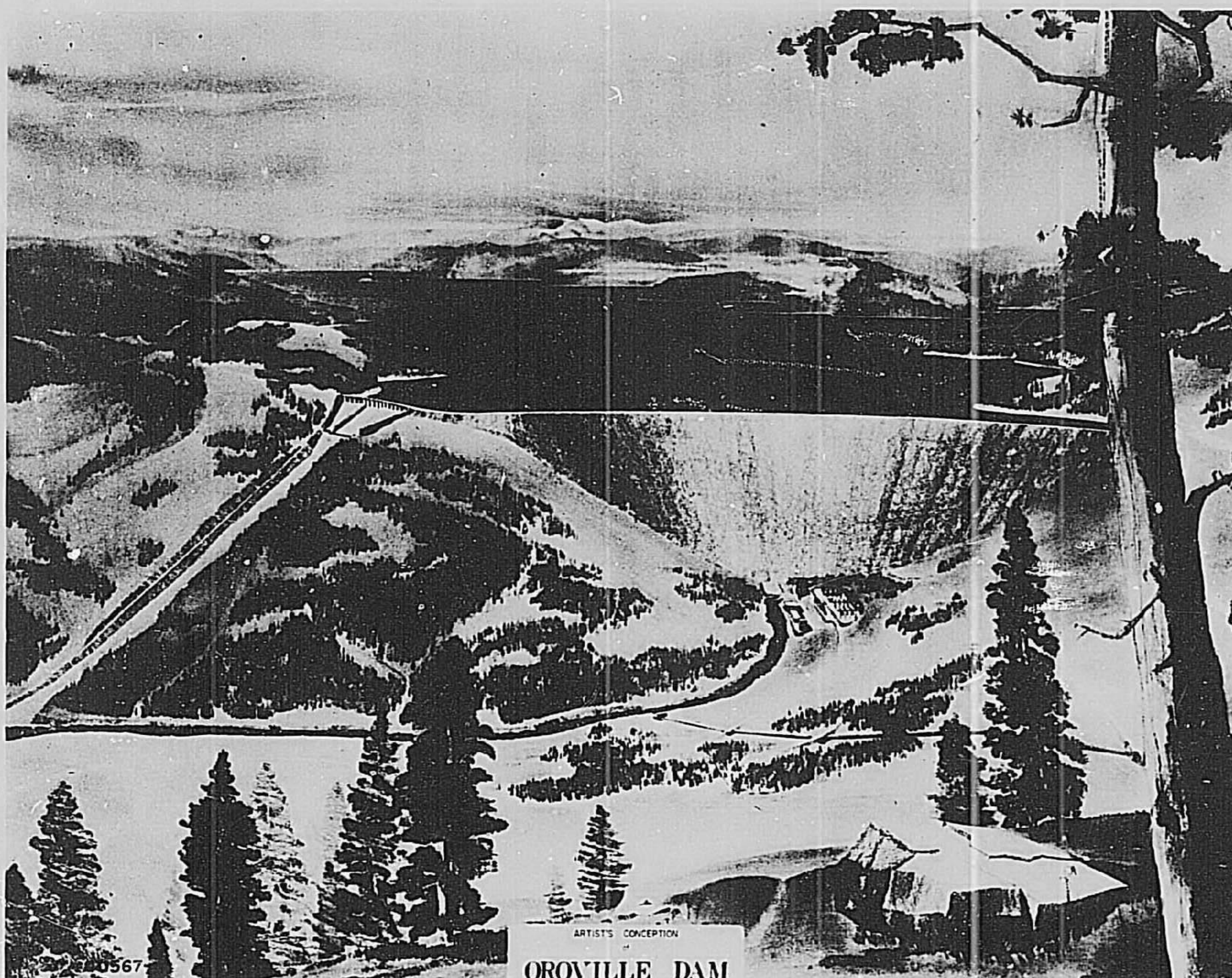


Report No. Hyd-549

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

September 15, 1965


ARTIST'S CONCEPTION
of
OROVILLE DAM

# PREFACE

Hydraulic model studies of features of Oroville Dam and Powerplant were conducted in the Hydraulic Laboratory in Denver, Colorado. The studies were made under Contract No. 14-06-D-3399 between the California Department of Water Resources and the Bureau of Reclamation.

The basic designs were conceived and prepared by the Department of Water Resources. Final designs were established through model studies that verified the adequacy of the basic designs, or led to modifications needed to obtain more satisfactory performance. The high degree of cooperation that existed between the staffs of the two organizations helped materially in speeding final results.

During the course of the studies Messrs. D. P. Thayer, G. W. Dukleth, and Arthur Bunas observed the tests and discussed the results. Close telephone liaison was maintained between the Bureau Laboratory and Mr. Paul Gilbert in Sacramento, thus assuring orderly progression of the tests and prompt exchange of pertinent information. Mr. K. G. Bucher, Hydraulics Unit, California Department of Water Resources, designed the model, supervised its construction, and conducted the preliminary tests of the program discussed in this report. When other pressing commitments required all of Mr. Bucher's time, the author completed the test program and prepared this final report.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
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BUILDING 53, DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY REFER TO: D-293

September 15, 1965

Mr. William E. Warne, Director
Department of Water Resources
State of California
Sacramento 2, California

Dear Mr. Warne:

I am pleased to submit Hydraulics Branch Report No. Hyd-549 which constitutes our final report on model studies conducted on the pressure-relief panels in the temperature control shutters of the powerplant intake towers at Oroville Dam. I believe this report will satisfy the requirements of your office for a comprehensive discussion of the test program.

Sincerely yours,

B. P. Bellport

B. P. Bellport
Chief Engineer

Enclosure

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## ABSTRACT

As a result of hydraulic model studies the relief panel and port recommended for the intake structures to prevent overpressures and structural damage to the temperature control shutters will open and close satisfactorily within the differential head range specified. Water for the left powerplant will flow through 2 parallel inclined 650-ft-long intake structures. A train of 13 temperature control shutters will be installed in each tower to form a roof. Shutters may be removed one at a time, starting with the uppermost, to release reservoir waters of desired temperature downstream. The studies were undertaken because inadvertent occurrences or an operational procedure might cause instantaneous head differentials in excess of the allowable maximum of 5 ft of water between the upper and lower side of the shutters. To prevent overpressures, relief panels will be installed in the lower temperature control shutters of each tower. The panels will be held closed by a torsion spring and will start to open at a 3.5-ft head differential and swing fully opened at a 4.6-ft differential. They will close at differentials less than 2.77 ft. Ninety-four panels will pass the maximum 8,600-cfs power demand in one tower with a 3.5-ft head differential across the shutters. The port with a convex rounding at the panel dropping edge and concave at the rising edge was selected as the best entrance configuration because it produced the highest torque at midrange.



DESCRIPTORS-- hydraulics/ model tests/ laboratory tests/ *intake towers/ intake structures/ discharge coefficients/ penstocks/ powerplants/ *relief valves/ head losses/ control structures/ flow control/ *ports/ hydrostatic pressures/ temperature control/ *torque/ panels/ research and development/ *hydraulic models/ hydraulic structures/ operations/ overloads/ damages
IDENTIFIERS-- *Oroville Dam Powerplant/ *inclined intake structures/ torque meters/ torsion springs/ *pressure relief panels/ head differential/ hydraulic design/ California/ water temperature selection

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Office of Chief Engineer
Division of Research
Hydraulics Branch
Denver, Colorado
September 15, 1965

Report No. Hyd-549
Author: D. Colgate
Checked by: W. P. Simmons
Reviewed by: W. E. Wagner
Submitted by: H. M. Martin

Subject: Hydraulic model studies of the pressure-relief panels in the powerplant intake structure--Oroville Dam--Department of Water Resources, State of California

## PURPOSE

The model study was made to develop a relief panel and relief port configuration with hydraulic characteristics that will assure full, rapid opening and prevent overpressures and structural damage to the temperature control shutters for the Oroville Dam powerplant intake structures.

## CONCLUSIONS

1. A 3-foot-long by 2-foot 10-3/4-inch-wide relief panel with the underside flush with the underside of the temperature control shutter, and with a hinge eccentricity of 2-3/4 inches, will start to open against a torque of 434 foot-pounds when subjected to a differential head of 3.5 feet.

2. The optimum configuration of relief panel and entrance shape is shown in Figure 16. When held near the closed position with a torsion spring exerting 434 foot-pounds1/ in the closed position and increasing linearly to 477 foot-pounds in the 90° open position, the panel will:

   a. Start to open at a 3.5-foot differential head (Figure 15).

   b. Open to 90° under a maximum differential head of 4.60 feet when no flow is occurring in the tower (the most disadvantageous condition for opening).

---

1/This torque assumes a panel without weight. Torque values shown in this report must be modified by the moment of force of the panel for every position of the panel.

c. Start to close from the 90° open position under a minimum differential head of 2.77 feet when a flow of 8,600 cfs is occurring in the tower (the most disadvantageous condition for closing).

3. At the 90° open position, one panel will pass 91.8 cfs at a differential head of 3.5 feet based on $C_d$ of 0.68 when no flow is occurring in the inclined towers (Figure 16). Ninety-four panels would be needed to furnish all of the demand for power (8,600 cfs) with a head differential of 3.5 feet across the temperature control shutters.

## INTRODUCTION

Oroville Dam is a key facility in the California water plan. The damsite is on the Feather River about 5-1/2 miles northeast of Oroville in north-central California (Figure 1).

Water for the underground powerplant will flow through two inclined intake towers before entering the power penstocks (Figures 2 and 6A). These intake towers are about 650 feet long and are inclined 27°45' from the horizontal to follow the natural ground surface.

Agricultural requirements downstream from the dam demand that the warmest available water be released during the irrigation season, and fishing interests require that cooler, but not necessarily the coldest available water be released during the fish spawning and hatching season. To meet these opposing demands, a train of 13 temperature control shutters will be installed to form the top, or roof, of each intake tower (Figure 3). These shutters are each 40 feet long with a 44-foot structural span, and may be removed one at a time starting with the uppermost one. Thus, by proper removal of the shutters during the irrigation season, the uppermost, or warmest, strata of water may be drawn from the reservoir regardless of reservoir water surface elevation. During fish spawning and hatching season shutters may be withdrawn to the proper temperature strata in the power pool and thus the required temperature water can be released through the powerplant.

The temperature control shutters (Figure 4) are designed to withstand an external (reservoir to intake tower channel) head differential of 5 feet. Excessive internal (intake tower channel to reservoir) head differentials may also occur. There is a possibility that, without some safety feature, an inadvertent or an operational procedure might cause head differentials in excess of the allowable maximum with resulting damage to the shutters. To prevent the damaging pressure differentials from occurring, relief panels will be installed in the three lower shutters in each tower. Internal relief panels will be installed in the lowest shutter, and external relief panels will be installed in the second and third shutters from the bottom. As an added precaution limited-strength tension bolts will be installed in the internal relief panels. These bolts will fail at an external head differential of 7 feet permitting the panels to open inwardly and act as additional external relief panels.

The external relief panels will be 3 feet long by 2 feet 10-3/4 inches wide (Figure 4). Torsion springs will hold the panels closed against head differentials up to 3.5 feet, and the panels must have hydraulic characteristics that will cause them to swing 90° open without exceeding a 5-foot head differential.* It is anticipated that by quickly opening to pass large quantities of water through the temperature control shutters, the relief panels will prevent damaging overloads from occurring.

The external relief panels were subjected to extensive model studies. These studies were made to: (1) determine experimentally the proper relief panel shape, entrance port configuration, and hinge position; (2) measure the torque imparted to the panel by the water for a range of head differentials across the panel with various flows through the intake tower under the shutters; and (3) calibrate the recommended panel-port configuration to permit determining the number of panels required to pass the maximum power requirement, 8,600 cfs for one intake.

## THE MODEL

A 1:4 scale model was used for the studies. The 14-foot-long by 4-foot-wide by 6-foot-deep head box was divided longitudinally by a rock baffle (Figures 5 and 6B). The portion of the box on the left side served as a stilling area for flow representing water in the reservoir. This flow passed uniformly through the baffle and into the right-hand compartment. The floor of this right-hand compartment represented the top of a temperature control shutter, and contained the modelled relief panel, including appropriate structural beams and supporting members (Figure 6C). A 2-foot-wide by 1-foot-deep flow passage was provided beneath this floor (shutter) so flows similar to those occurring in the intake towers during turbine operation could be represented. Finally, an adjustable invert was provided beneath and downstream from the relief panel so the area, and hence flow velocity, could be controlled to the proper values as water was furnished to the tower through the relief panel.

*In the final design, stops are included to limit the opening to 60° to reduce deflection in the torsion springs.

Water was supplied to the reservoir portion of the model by an 8-inch portable pump, controlled with a manually operated 8-inch gate valve, and measured with an 8-inch orifice-venturi meter. Water was furnished to the tower portion of the model through a 12-inch conduit from the permanently installed laboratory system, controlled with a hydraulically actuated 12-inch gate valve, and measured with a cylindrical pitot tube.

Two double-side-channel-type overflow weirs with a total crest length of 24 feet 8 inches were mounted in the reservoir as a wasteway to provide a nearly constant reservoir elevation while variable discharges passed through the panel opening. Head differentials across the shutter-panel bulkhead were controlled by a valve in the intake tower (lower) portion of the model.

The relief panel was mounted in the port so that in the closed position the bottom of the panel was flush with the underside of the temperature control shutter (Figure 6C). For the initial test the hinge point on the model was offset 1.250 inches above the bottom plane of the panel and with an eccentricity of 0.688 inch from the transverse centerline. These values represented 5 inches offset and 2.75 inches eccentricity, prototype. The axles rotated in teflon bearings.

The torque on the panel was measured with a meter that consisted of a 5-inch-long, 1/4-inch-diameter stainless steel rod machined to 1/4-inch square in the middle 2 inches (Figure 7). An A-19, SR-4-type strain gage was installed on each face of the square portion of the rod in such a manner that torsion of the rod would be additive on the readout from the gages and bending response would cancel out.

One end of the torque meter was fixed to the panel, the other to a miter gear which could be turned to set and hold the panel in any desired position. The two cylindrical ends of the meter shaft passed through teflon bearings.

## INVESTIGATION

### Torque

The torque loads exerted upon the relief panel by the hydrodynamic forces of the water passing by it were of primary interest in the study. The procedure followed to obtain the torque data was as follows:

1. With no flow through the tower or panel port, but with the system submerged, the panel was moved to a desired position and a zero reading set on the torque meter readout recorder. This assured that any torque recorded while water was flowing through the model would reflect hydrodynamic forces only.

2. The flow through the tower was adjusted as desired.

3. The head differential ($\Delta H$) across the temperature control shutter was set.

4. The flow into the reservoir was adjusted so that, in addition to the discharge through the panel port, some flow passed over the reservoir weir.

5. After rechecking to assure that a change in torque had not changed the panel position, a torque readout was recorded.

The parameters, based on Froude relationships, for computation of prototype results are:

Head differential

$$\Delta H_p = 4\ \Delta H_m \text{ (feet of water)}$$

$$\left(H_p = N\ H_m\right)$$

Panel discharge

$$Q_p = 32\ Q_m \text{ (cfs)}$$

$$\left(Q_p = N^{5/2}\ Q_m\right)$$

Tower discharge

$$Q_p = 1,136\ Q_m$$

This relationship is needed because only part of the tower was represented:

Actual area of model tower = 2 square feet
Area of prototype tower = 1, 136 square feet
True-scaled area of model tower $= \frac{A}{N^2} = \frac{1,136}{(4)^2} = 71$ square feet

Applying the ratio of true-scaled tower area to modelled tower area,

$$Q_p = \frac{(71)}{2} Q_m N^{5/2}$$

or

$$Q_p = 1,136\ Q_m$$

Torque

$$T_p = 256\ T_m\ \text{(ft-lbs)}$$

$$\left(T_p = N^4 T_m\right)$$

Where:

Model scale = 1:4 (N = 4)
Subscript "p" indicates prototype
Subscript "m" denotes model
$\Delta H$ = head differential across the temperature control shutters in feet of water
Q = discharge in cfs
T = torque in foot-pounds

The torque measurements were made with various port and panel configurations.

Port Configuration

The criterion for acceptable configuration for the panel ports was its contribution to torque upon the panel. Thus, a configuration that was sensitive to flow through the panel and resulted in maximum torque at all openings was desired. All port tests were made with no flow through the intake tower, Panel No. 1 (Figure 8, Test 1), and a 5-foot head differential2/ across the temperature control shutter.

Six entrance configurations (referred to as Tests 1 through 4B, Figures 8 and 9)3/ were tested with panel opening ranging from 0° to 90° in 15°

2/Unless otherwise stated, the discharges, pressures, dimensions, and torque values in this report are for the prototype.
3/Entrance and panel configurations are referred to by test number and panel number, respectively, to be consistent with preliminary information sent to the State of California.

increments. The results show that the midopen range was critical because a significantly lower torque occurred in this range than at larger or smaller openings (Figure 10). To assure that the panels would open to the 90° position without a $\Delta H$ greater than 5 feet, higher midrange torque was needed. The configuration changes on the sides of the opening (Figure 9, Tests 4, 4A, and 4B) produced increased torque at larger panel openings, but resulted in no beneficial effects in the critical range of 30° to 60°. Therefore, plans to modify the sides of the opening were abandoned. The port configuration with convex rounding at the dropping edge of the panel and concave rounding at the rising edge (Test 3, Figure 8) was the best entrance configuration tested because it produced the highest torque at midrange. This entrance shape was installed permanently in the model for the test phases on relief panel configuration.

## Panel Configuration

The six panel configurations tested are shown in Figures 11 and 12. All panel tests were made with Entrance No. 3 (Figure 8, Test 3). Panel No. 1 had a curvature of 3-foot radius with a 3-1/2-inch rise on the dropping half of the panel. There were no Panels No. 2 through 5. Panels No. 6 and 7 (Figure 11, Tests 6 and 7) were generally similar to Panel No. 1; however, Panel No. 6 had a curvature of 2-foot radius with a 3-1/2-inch rise, and No. 7 had a curvature of 2-foot radius with a 6-inch rise. Panel No. 8 (Figure 11, Test 8) had a curvature of 2-foot radius with a 6-inch rise on the dropping half of the panel and the trailing edge was drawn away from the port edge to allow greater flow to pass this area at small panel openings. Panel No. 9 (Figure 11, Test 9) was the same as Panel No. 8 on the dropping half, but had a shaped flow surface on the rising edge. Panel No. 10 (Figure 11, Test 9A) included a chamfered or sloped leading edge relative to flow in the tower under the shutters to obtain greater turning force from reaction from the intake tower flow. Photographs of each of the panels tested are shown in Figure 12.

The results of the panel shape studies are shown in Figure 13. The values shown are for a 5-foot differential across the temperature control shutters and no flow through the tower upstream from the relief panel. Panel No. 7 exhibited the flattest and most desirable torque curve.

Comparison of the curves for Panels No. 8 and 9 (Figure 13) shows that a beneficial torque increase was obtained at the larger panel openings by the shaped flow surface on the rising edge of the panel. However, the rising edge shape had no beneficial effect at midrange opening and was not considered to be a desirable feature.

Panel No. 10 was tested with tower flow because the chamfered edge of the panel was designed to derive a turning force from the flow of water in the intake tower. With a $\Delta H$ of 5 feet and a tower flow of 7,000 cfs, the torque on Panel No. 10 was 580 foot-pounds at 90° panel opening. However, additional torque over that with no flow in the intake tower was nil at openings smaller than 50°. Therefore, the chamfered edge was not considered further.

Entrance No. 3 and Panel No. 7 produced the most desirable combination with relatively high torque in the critical midrange openings (Figure 13). For a complete picture of the torque characteristics, a series of tests was performed in which panel position, head differential across the temperature control shutters, and discharge through the intake tower were varied (Figure 14). The torque for any reasonable combination of panel position, $\Delta H$, and tower discharge may be determined from this chart. Satisfactory performance is indicated throughout the operating range, and this design combination is recommended for installation at Oroville Dam.

The action of the recommended pressure-relief panel and port configuration is defined in Figure 15. An assumption is made that the torsion spring exerts 434 foot-pounds with the panel at the closed position, and increases linearly to 477 foot-pounds (10 percent increase) with the panel 90° open.

With no flow through the tower, the panel will start to open at a $\Delta H$ of 3.5 feet, but an increase of $\Delta H$ to 4.6 feet is required to swing the panel past the 40° position. At larger panel openings the required $\Delta H$ decreases, and, provided a $\Delta H$ of 4.6 feet has been reached, will swing fully opened (90°) and remain fully opened as long as $\Delta H$ remains above 3.67 feet. For the closing cycle, as $\Delta H$ decreases from 3.67 to 3.47 feet, the panel will swing to about 78°, from which point it will swing fully closed.

With flow through the tower, and hence along the underside of the shutters, the differential head required to swing the relief panels open is less than the head required with no flow through the tower except at the closed position. The differential head required for proper operation of the panel for any tower flow may be determined from Figure 15.

## Discharge Coefficients

Discharge coefficient curves were determined for the recommended design for a range of panel positions and intake tower discharges (Figure 16). In these tests the reservoir head was maintained at a stage below the constant head weir crest. The results show that a discharge coefficient of 0.68 will occur with the panel 90° open and no flow through the tower. On the basis of a 3.5-foot head differential, a discharge of 91.8 cfs can occur through one 3-foot 5/8-inch by 2-foot 11-3/8-inch port. Ninety-four panels would be needed to furnish all the water for power demand (8,600 cfs and no flow through the intake tower) with a head differential of 3.5 feet across the temperature control shutters and all panels opened 80° to 90°.


## Summary

The recommended pressure-relief panel and port shown in Figure 16 will open and close satisfactorily within the differential head range specified for the temperature control shutters. Ninety-four panels will be required to pass the maximum power demand of 8,600 cfs at a head differential of 3.5 feet. The panels will swing fully open with a 4.6-foot differential head when no flow occurs through the tower (the most disadvantageous condition for the opening cycle). The panels will close if the differential head drops to about 2.77 feet with 8,600 cfs flowing through the tower (the most disadvantageous conditions for the closing cycle).

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4. "Hydraulic Model Studies of the Penstock Intake Control Structure for Oroville Dam," Report No. Hyd-509, by K. G. Bucher

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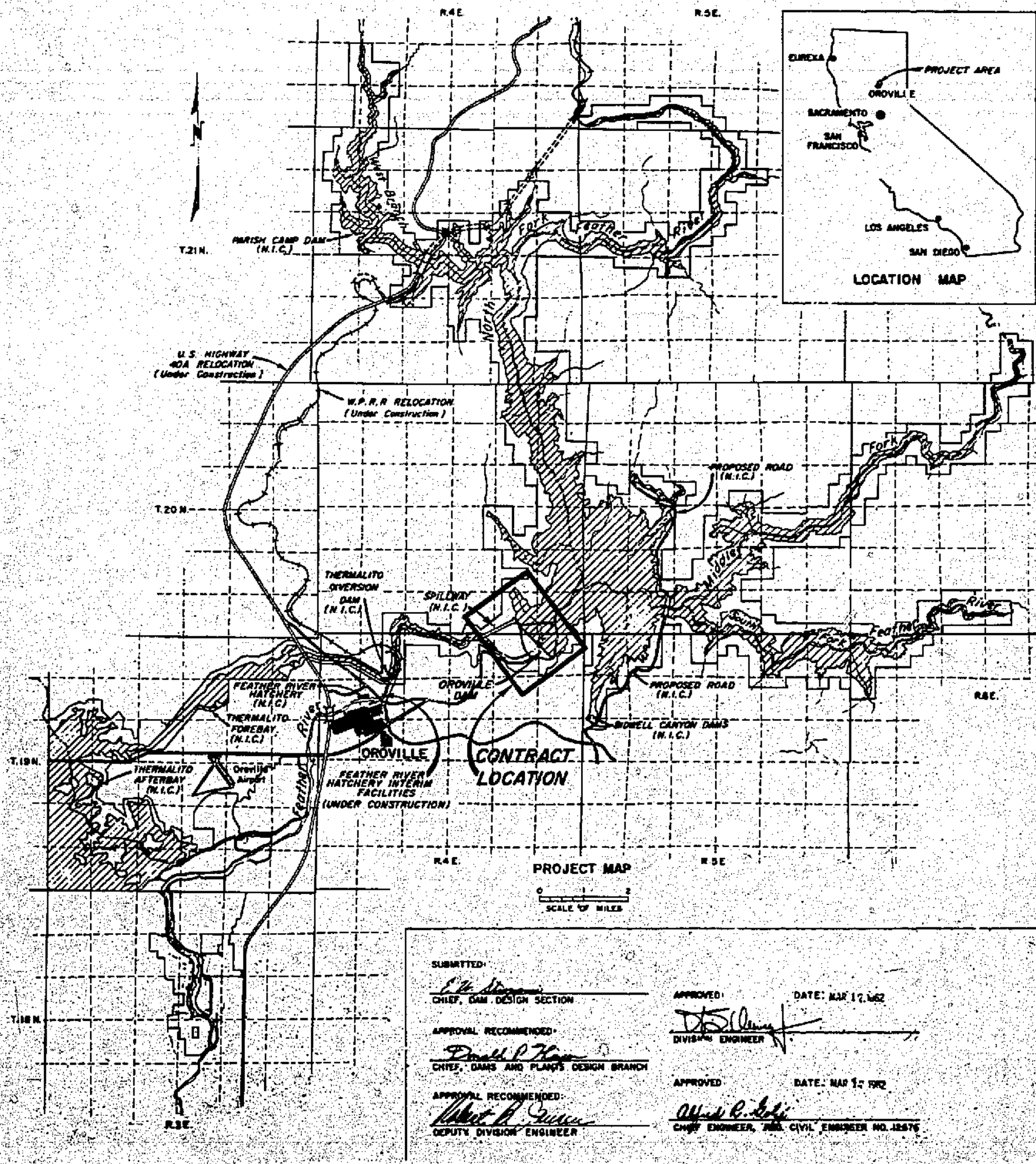
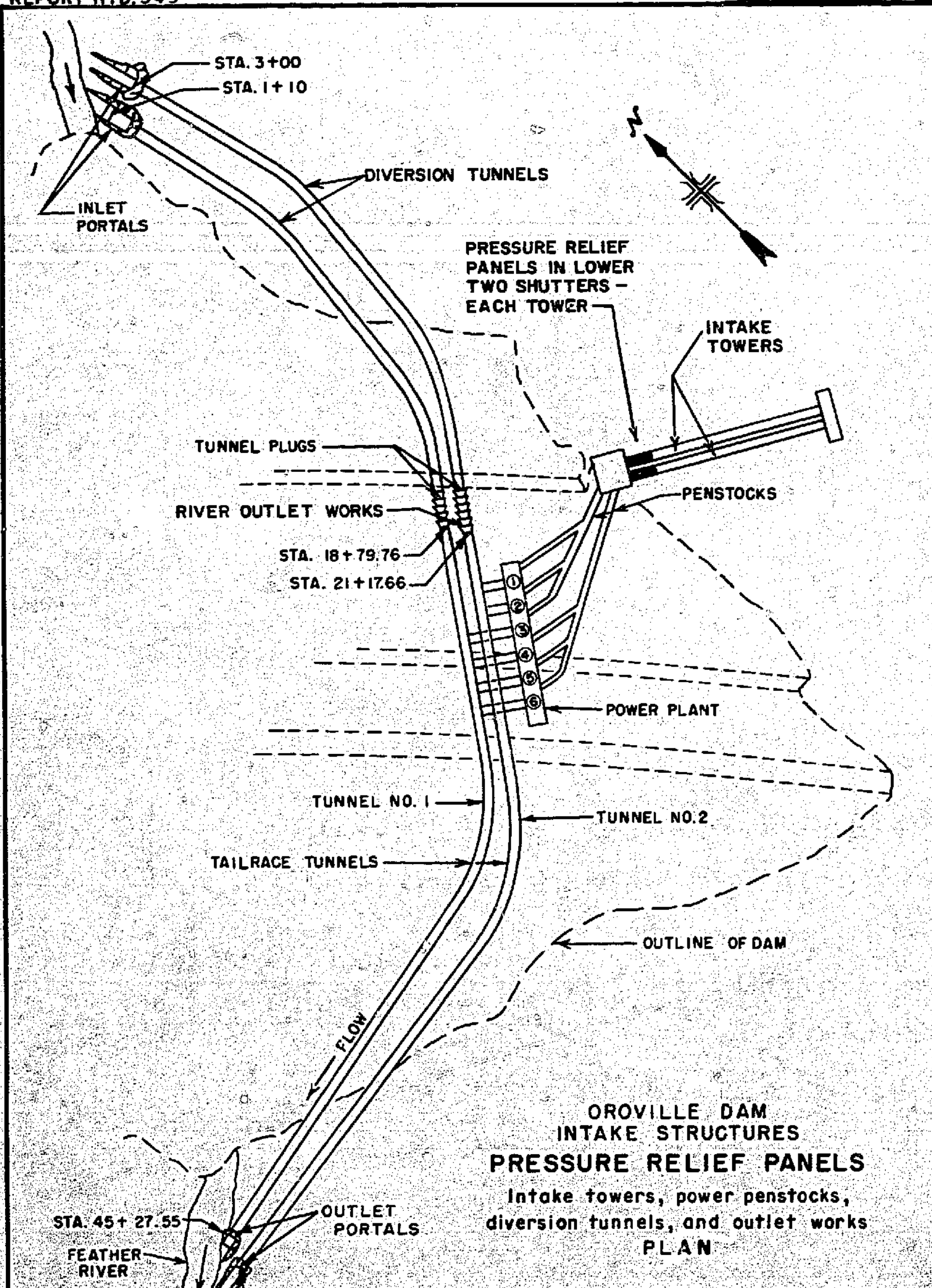
6. "Hydraulic Model Studies of the Downpull Forces on the Oroville Dam Powerplant Intake Gates," Report No. Hyd-540, by K. G. Bucher

FIGURE I



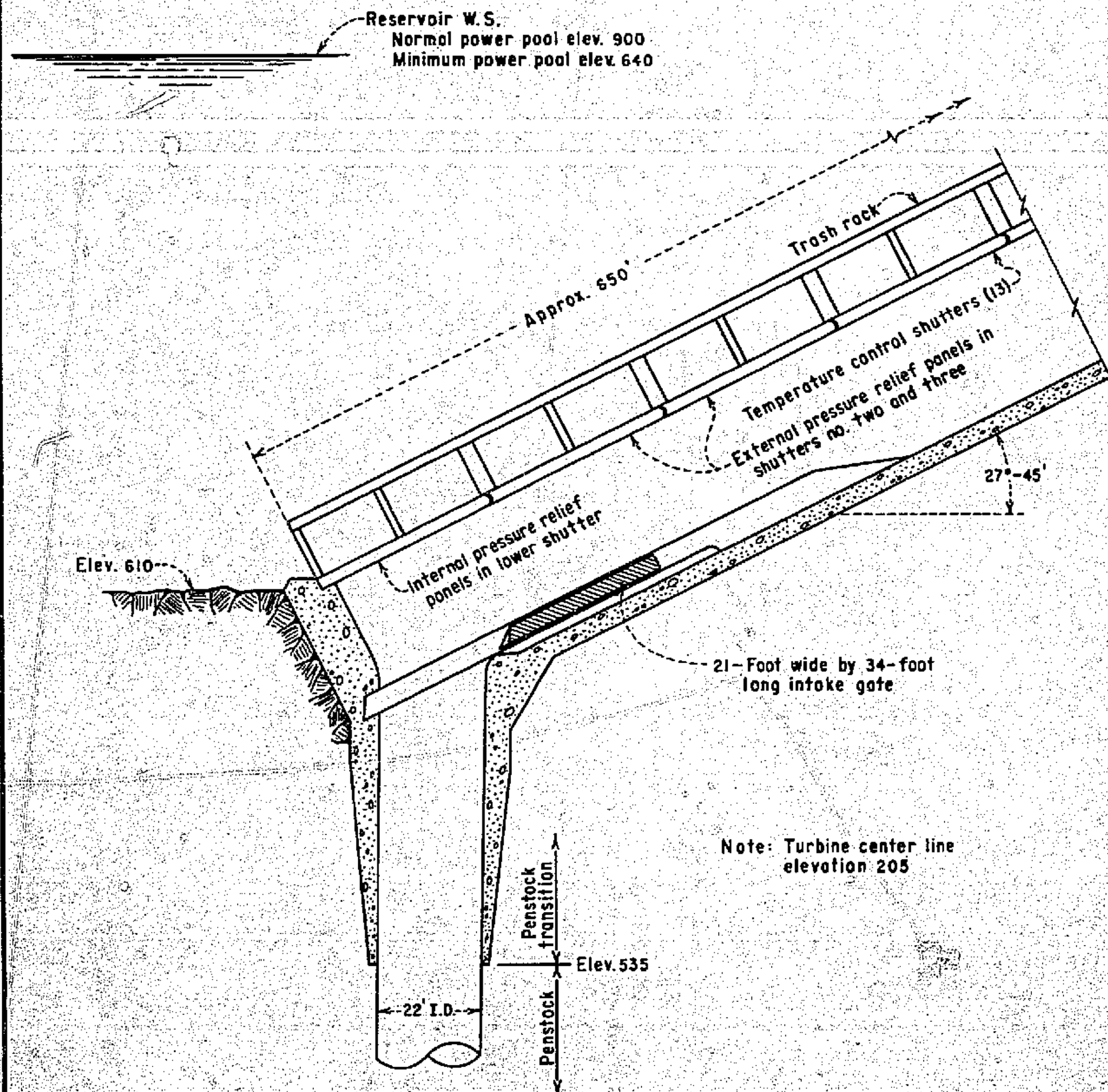
R.4 E.
R.5 E.
N
LOCATION MAP
EUREKA
PROJECT AREA
OROVILLE
SACRAMENTO
SAN FRANCISCO
LOS ANGELES
SAN DIEGO
PARISH CAMP DAM (N.I.C.)
T.21 N.
North
Feather
River
U.S. HIGHWAY 40A RELOCATION (Under Construction)
W.P.R.R. RELOCATION (Under Construction)
PROPOSED ROAD (N.I.C.)
T.20 N.
THERMALITO DIVERSION DAM (N.I.C.)
SPILLWAY (N.I.C.)
Middle
Fork
South
Fork
Feather
River
OROVILLE DAM
PROPOSED ROAD (N.I.C.)
R.6 E.
FEATHER RIVER HATCHERY (N.I.C.)
THERMALITO FOREBAY (N.I.C.)
BIDWELL CANYON DAMS (N.I.C.)
OROVILLE
CONTRACT LOCATION
T.19 N.
THERMALITO AFTERBAY (N.I.C.)
Oroville Airport
FEATHER RIVER HATCHERY INTERIM FACILITIES (UNDER CONSTRUCTION)
Feather River
PROJECT MAP
SCALE OF MILES
T.18 N.
R.3 E.
SUBMITTED:
CHIEF, DAM DESIGN SECTION
APPROVAL RECOMMENDED:
CHIEF, DAMS AND PLANTS DESIGN BRANCH
APPROVAL RECOMMENDED:
DEPUTY DIVISION ENGINEER
APPROVED:
DATE: MAR 12 1962
DIVISION ENGINEER
APPROVED
DATE: MAR 12 1962
CHIEF ENGINEER

FIGURE 2
REPORT HYD. 549




OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
Intake towers, power penstocks, diversion tunnels, and outlet works
PLAN

684




SECTION ON INCLINED INTAKE TOWER CENTERLINE

OROVILLE DAM
INTAKE STRUCTURES
**PRESSURE RELIEF PANELS**
Intake Structure
Elevation

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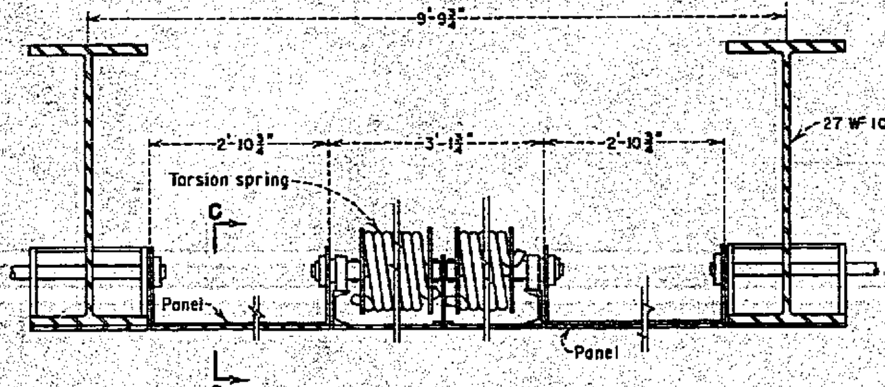
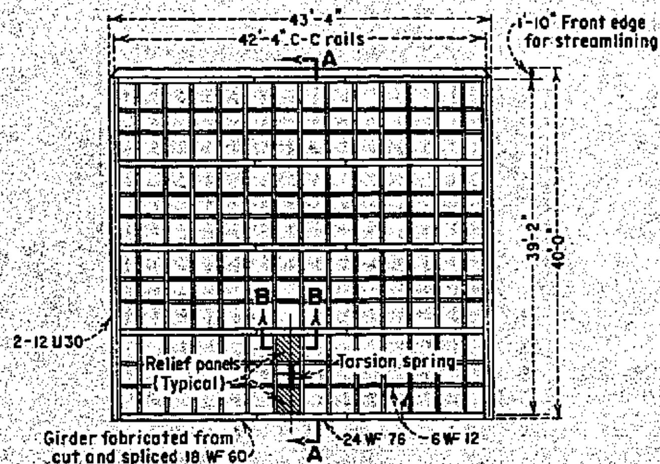
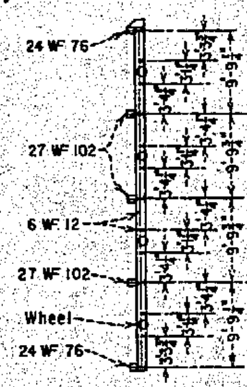


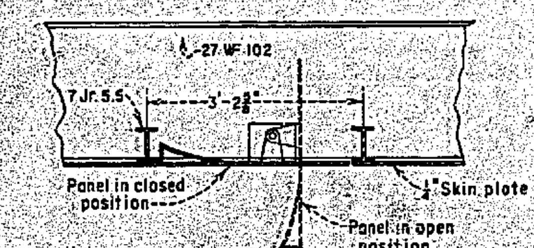

ASSEMBLY DETAIL




TOP VIEW
TEMPERATURE CONTROL SHUTTER




SECTION A-A

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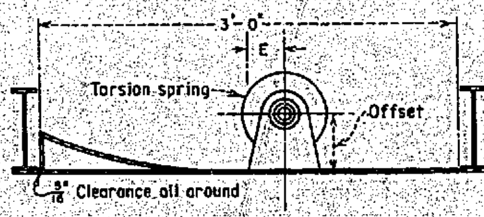
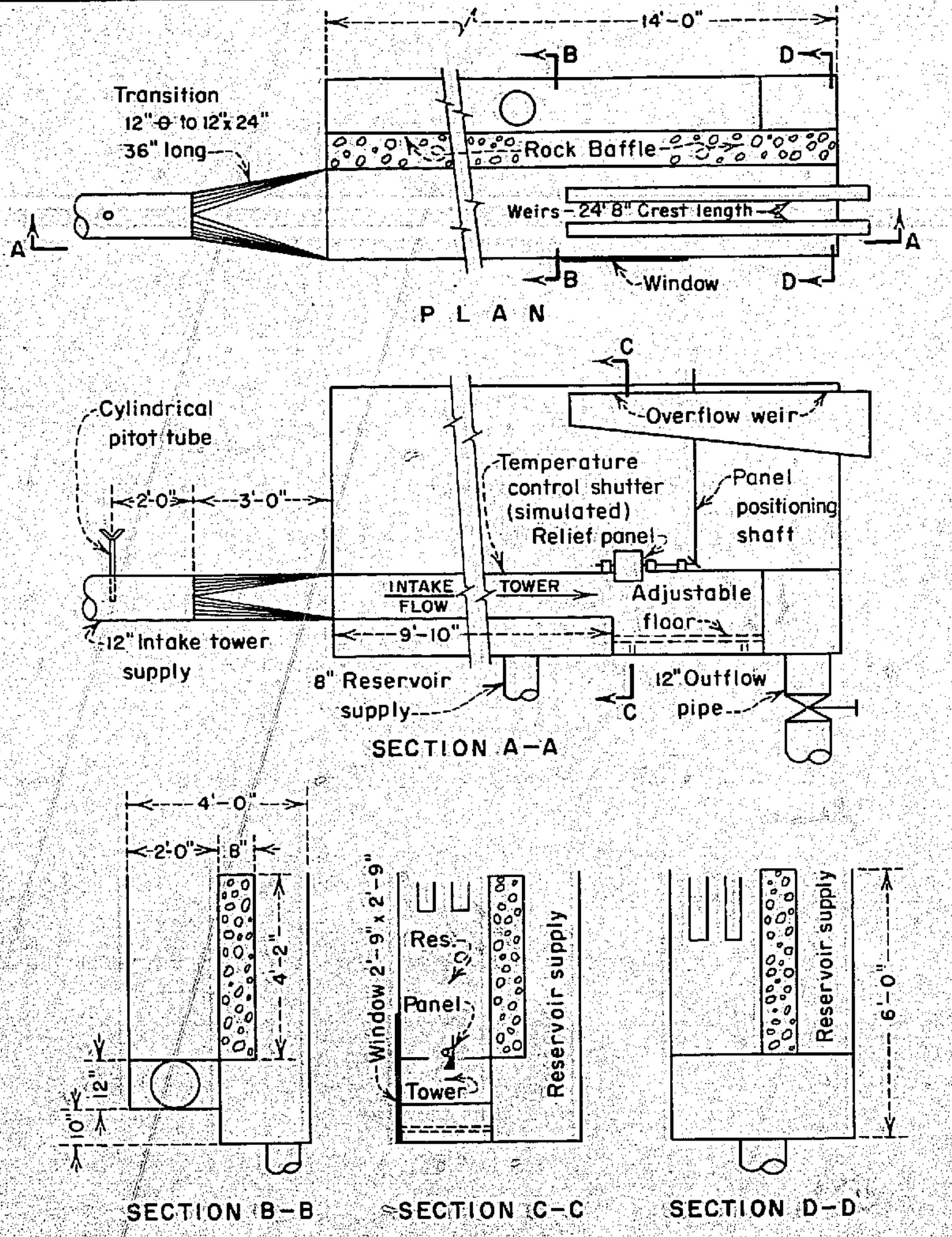



SECTION C-C

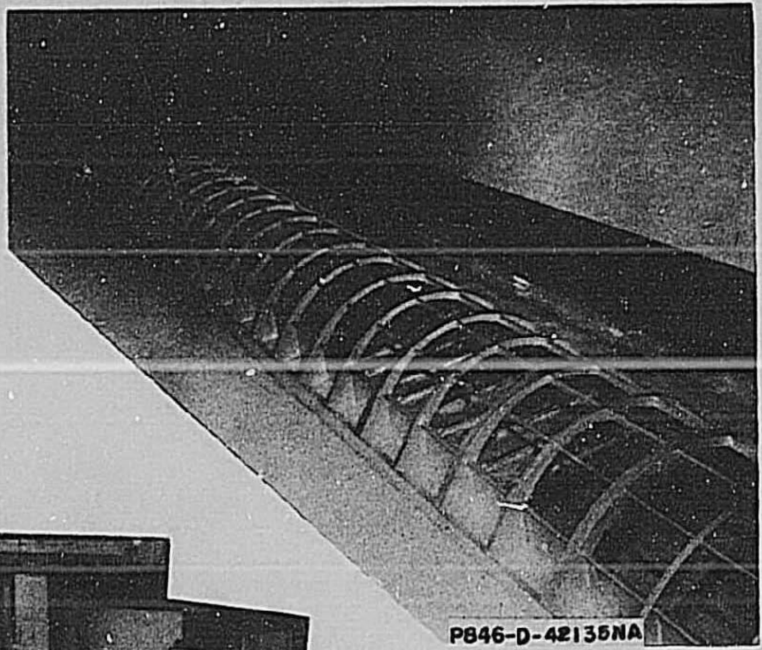
OROVILLE DAM
INTAKE STRUCTURES
**PRESSURE RELIEF PANELS**
Relief panel and torsion spring installation
PRELIMINARY



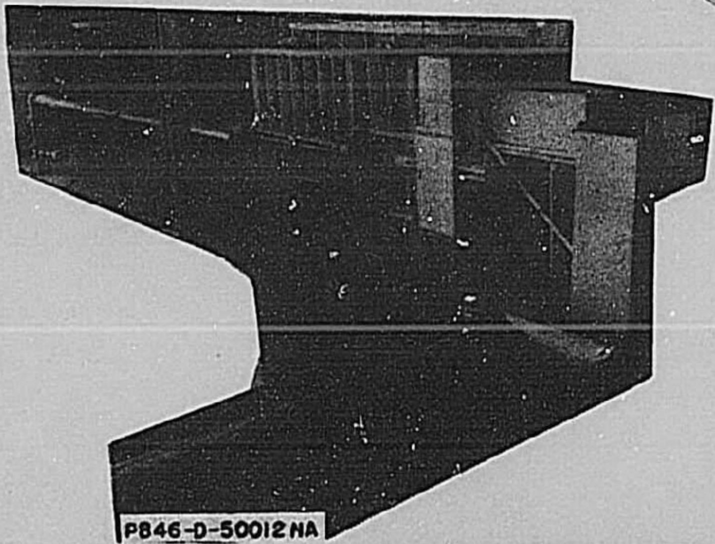

OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
1:4 SCALE MODEL
Model details

684

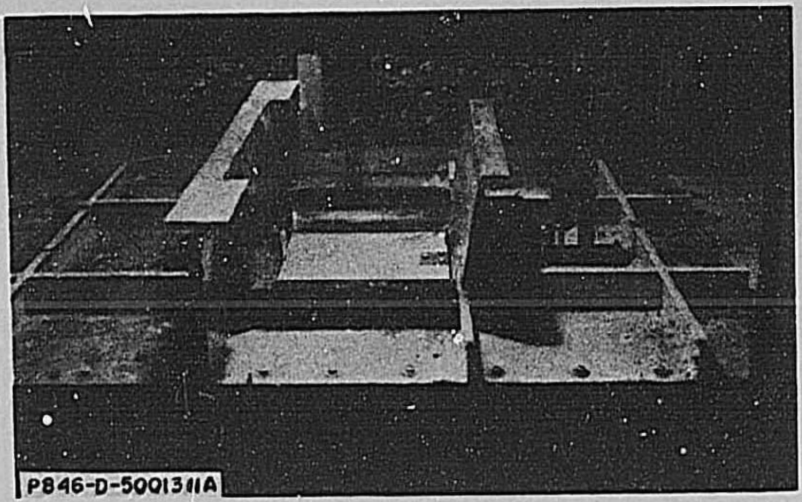
Figure 6
Report Hyd-549




A. Left intake structure with trashrack. (1:24 scale model)



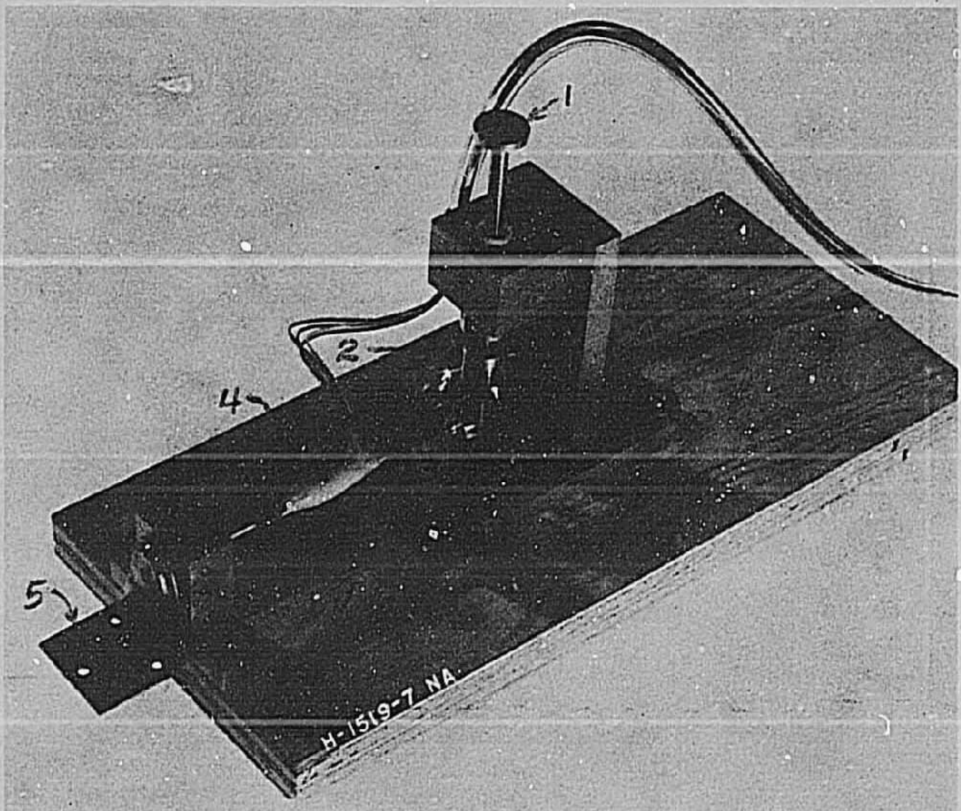

B. Model for relief panel studies.




C. Panel and port, 1:4 scale model.

OROVILLE DAM

Intake structures
Pressure-relief panels
General model installation




P846-D-50014NA

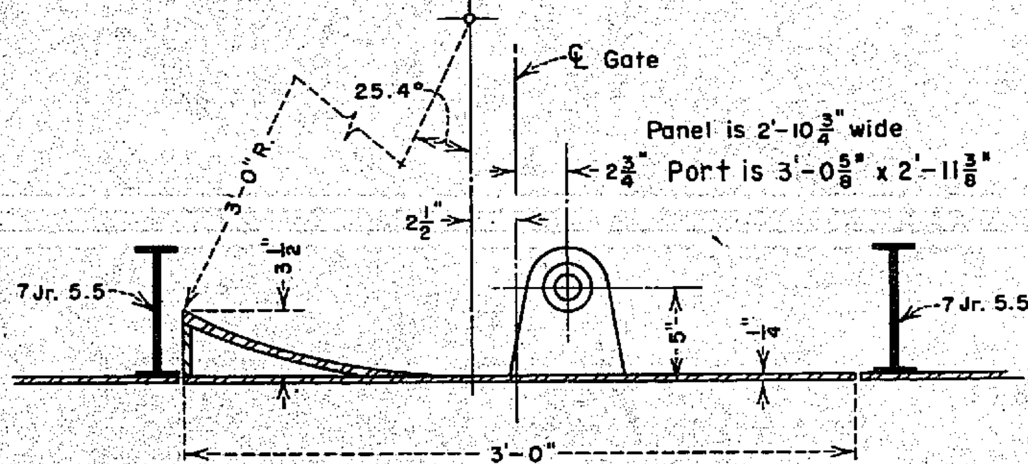
TORQUE METER

1. Panel position control shaft
2. Miter gears
3. Teflon bearing
4. SR-4 strain gage complex
5. Panel suspension plate

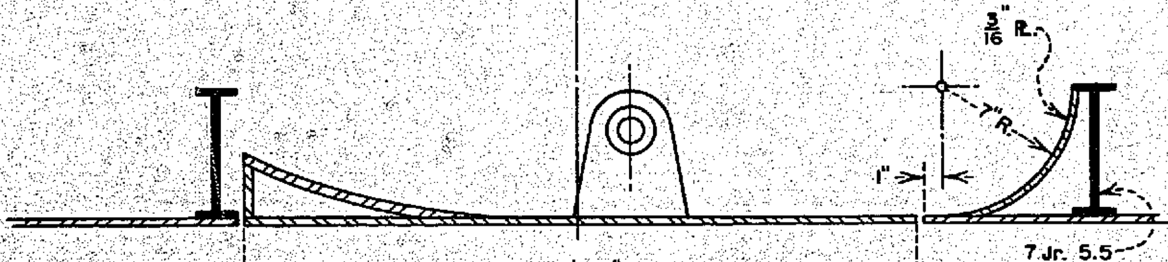
OROVILLE DAM

Intake structures
Pressure-relief panels

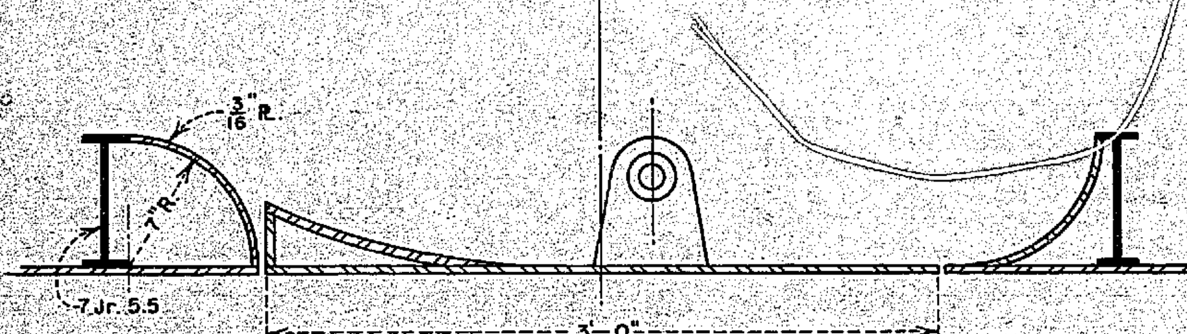
TORQUE METER




TEST NO.1, PANEL NO.1, ENTRANCE NO.1

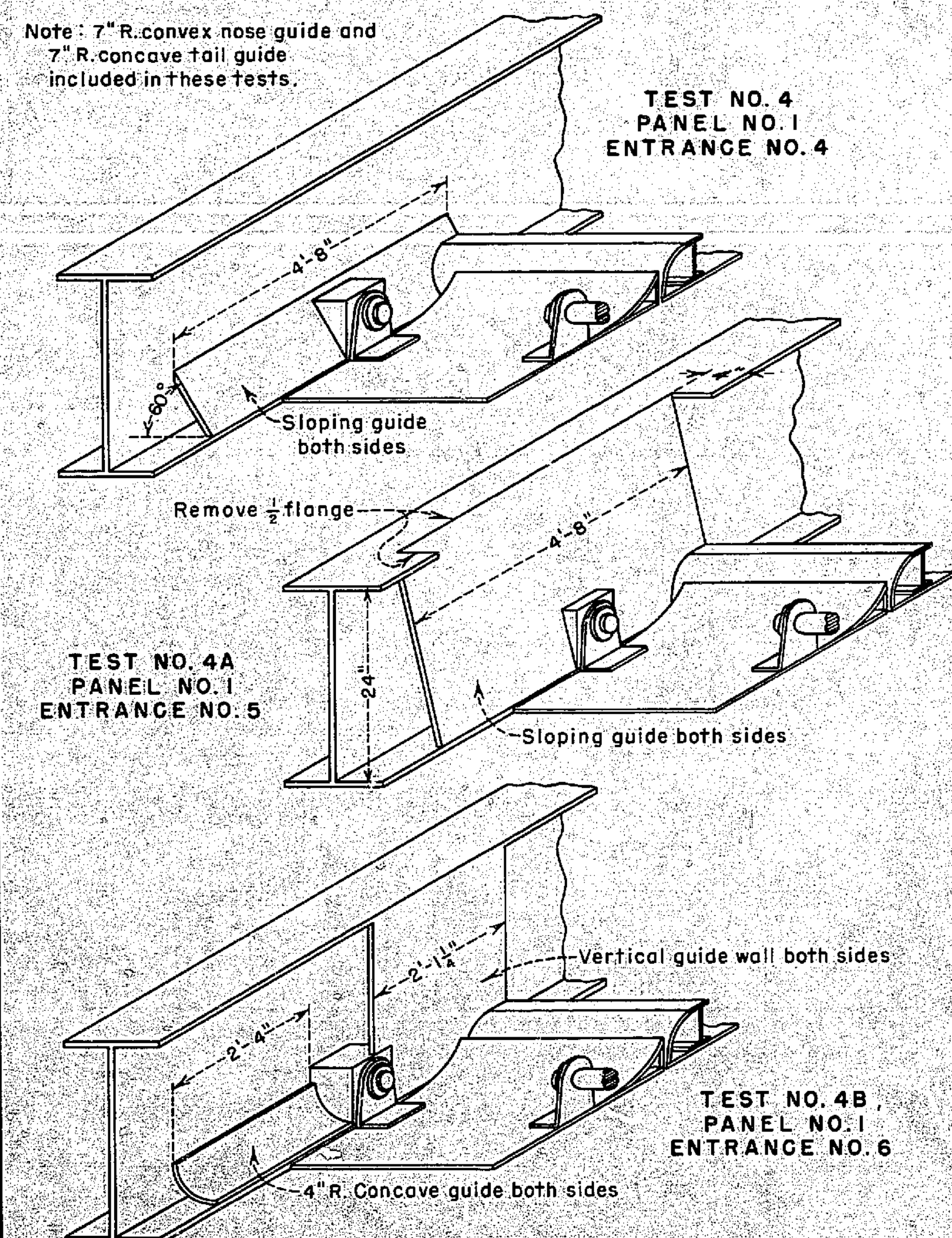



TEST NO.2, PANEL NO.1, ENTRANCE NO.2




TEST NO.3, PANEL NO.1, ENTRANCE NO.3

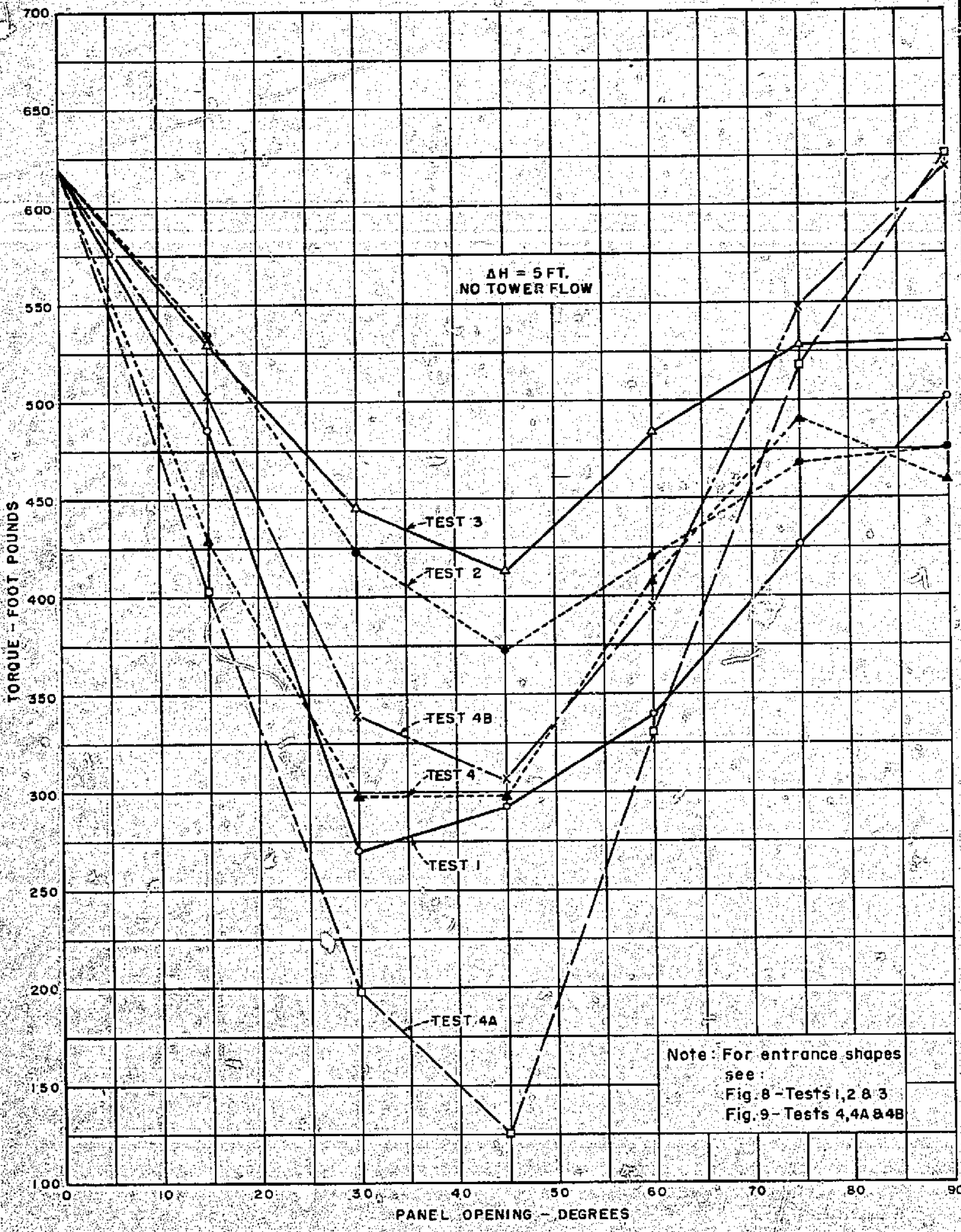
OROVILLE DAM
INTAKE STRUCTURES
**PRESSURE RELIEF PANELS**
1:4 SCALE MODEL
Panel No. 1
Entrance Nos. 1, 2, and 3




OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
1 : 4 SCALE MODEL
Panel No. 1
Entrance Nos. 4, 5 and 6

684

FIGURE 10
REPORT HYD-549




OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
1:4 SCALE MODEL
Torque characteristics with panel No. 1
and various entrances

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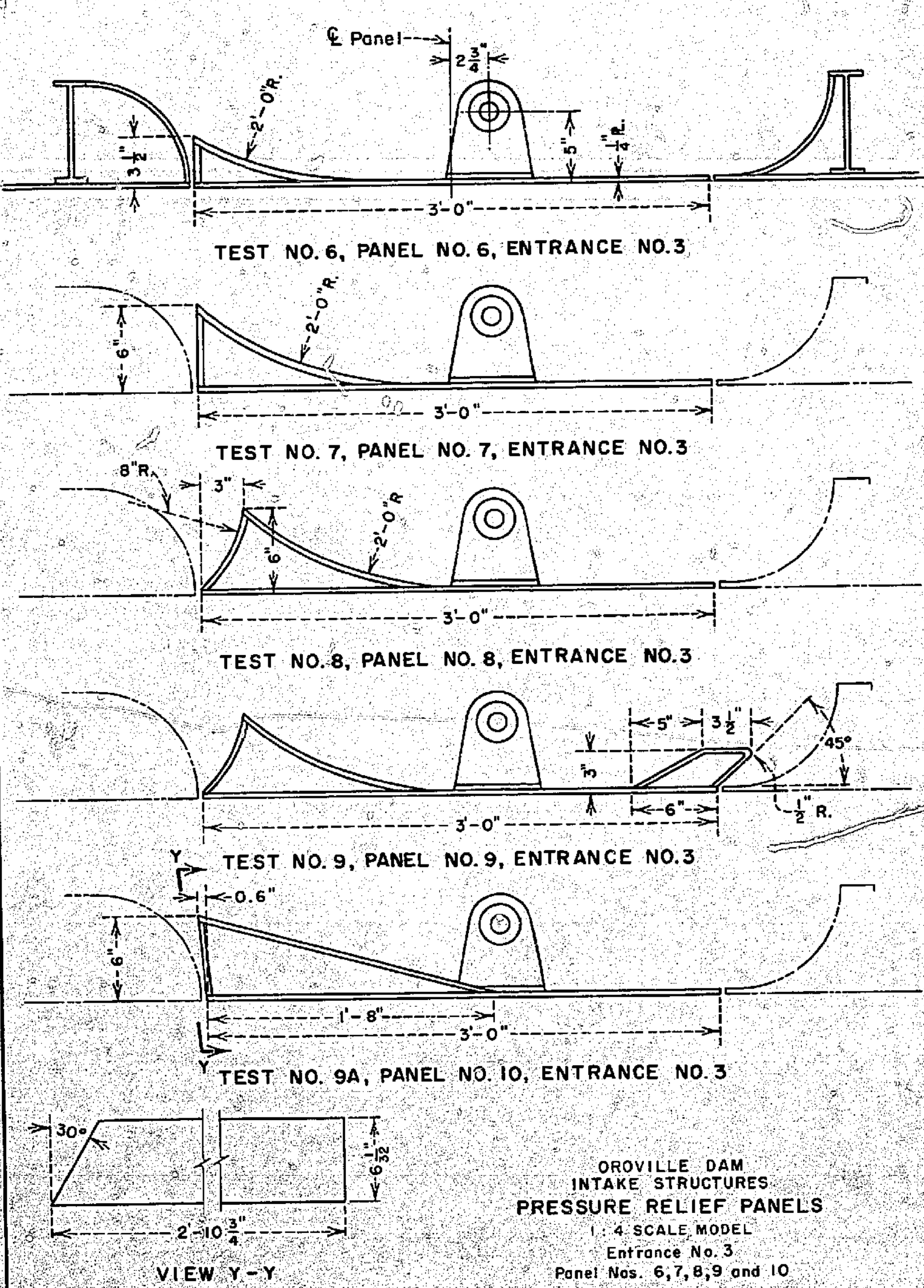


OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
1:4 SCALE MODEL
Entrance No. 3
Panel Nos. 6, 7, 8, 9 and 10

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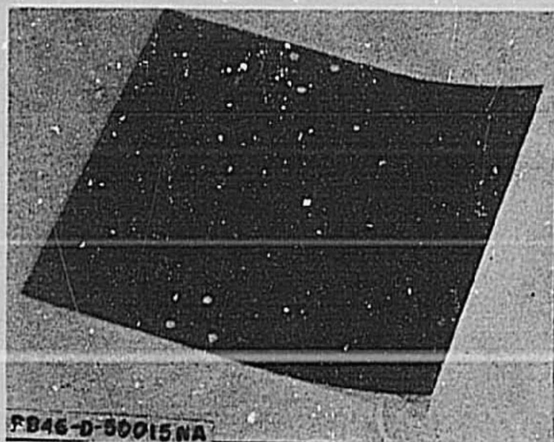
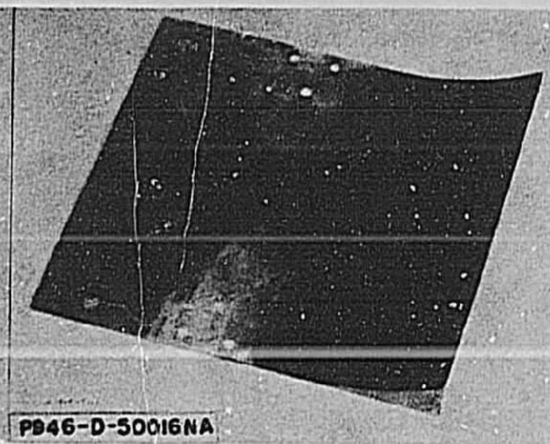
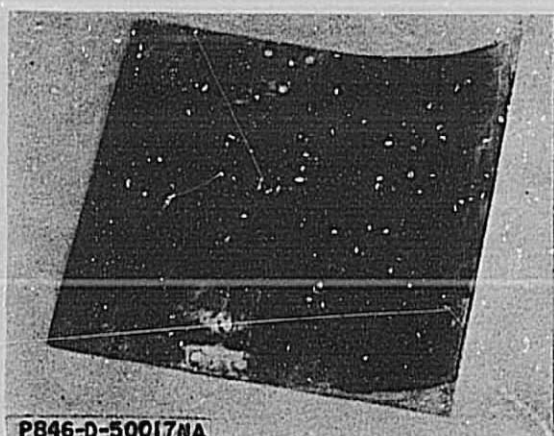
Figure 12
Report Hyd-549



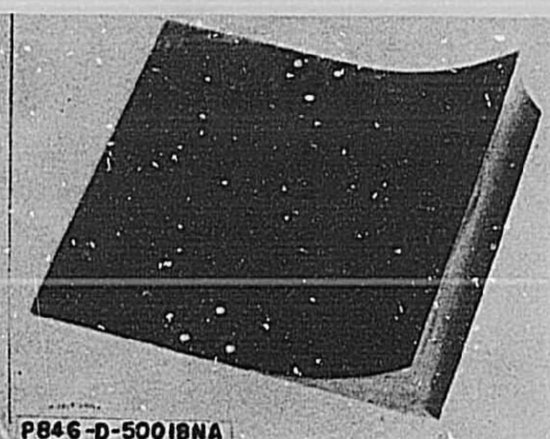

Panel No. 1



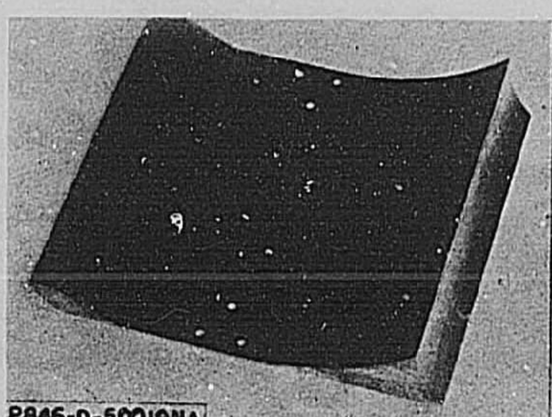

Panel No. 6



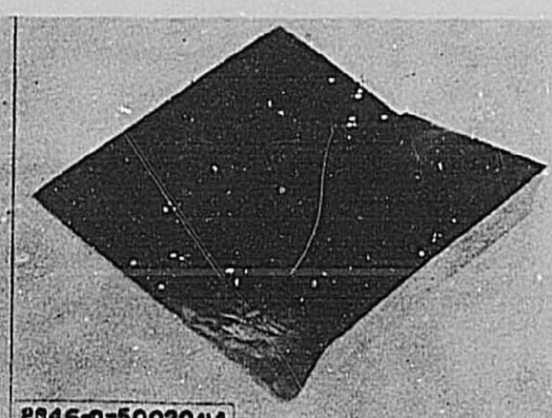

Panel No. 7




Panel No. 8



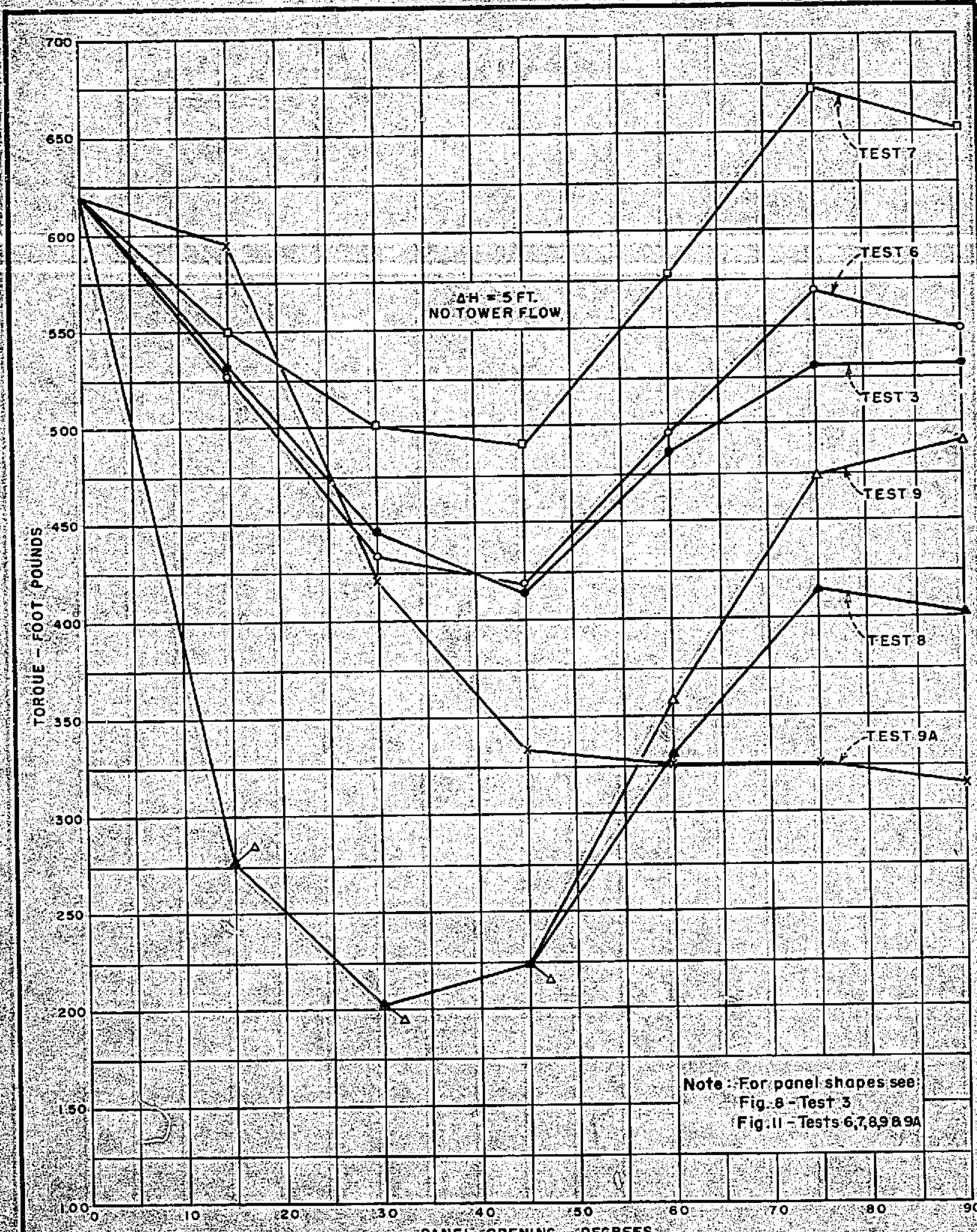

Panel No. 9




Panel No. 10

OROVILLE DAM

Intake structures
Pressure-relief panels
Photographs of panels
1:4 scale model




OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
1:4 SCALE MODEL
Torque characteristics with entrance No. 3
and various panels

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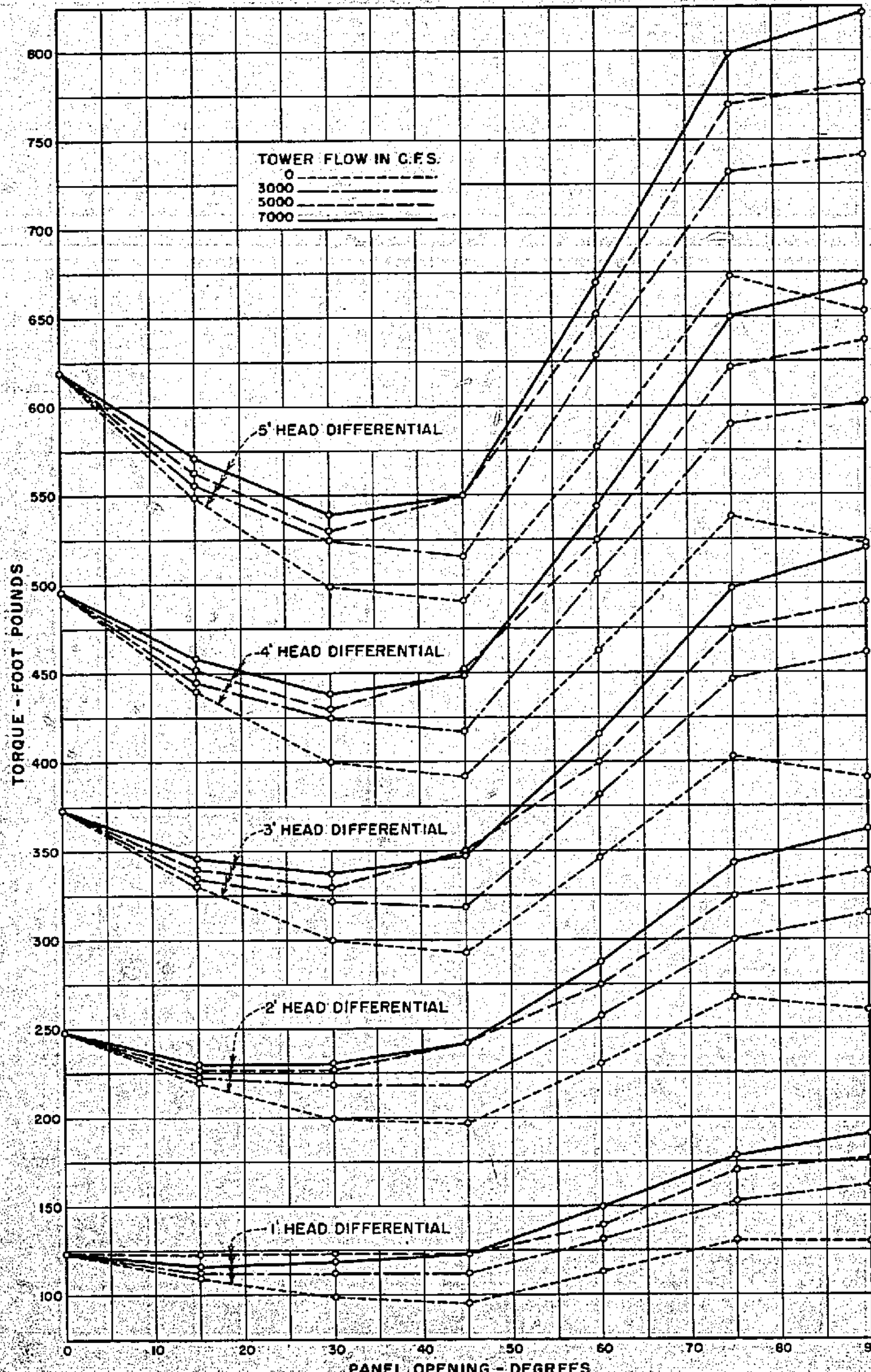
FIGURE 14
REPORT HYD-549




OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
1:4 SCALE MODEL
Torque values with entrance No.3 and panel No.7
(Recommended)

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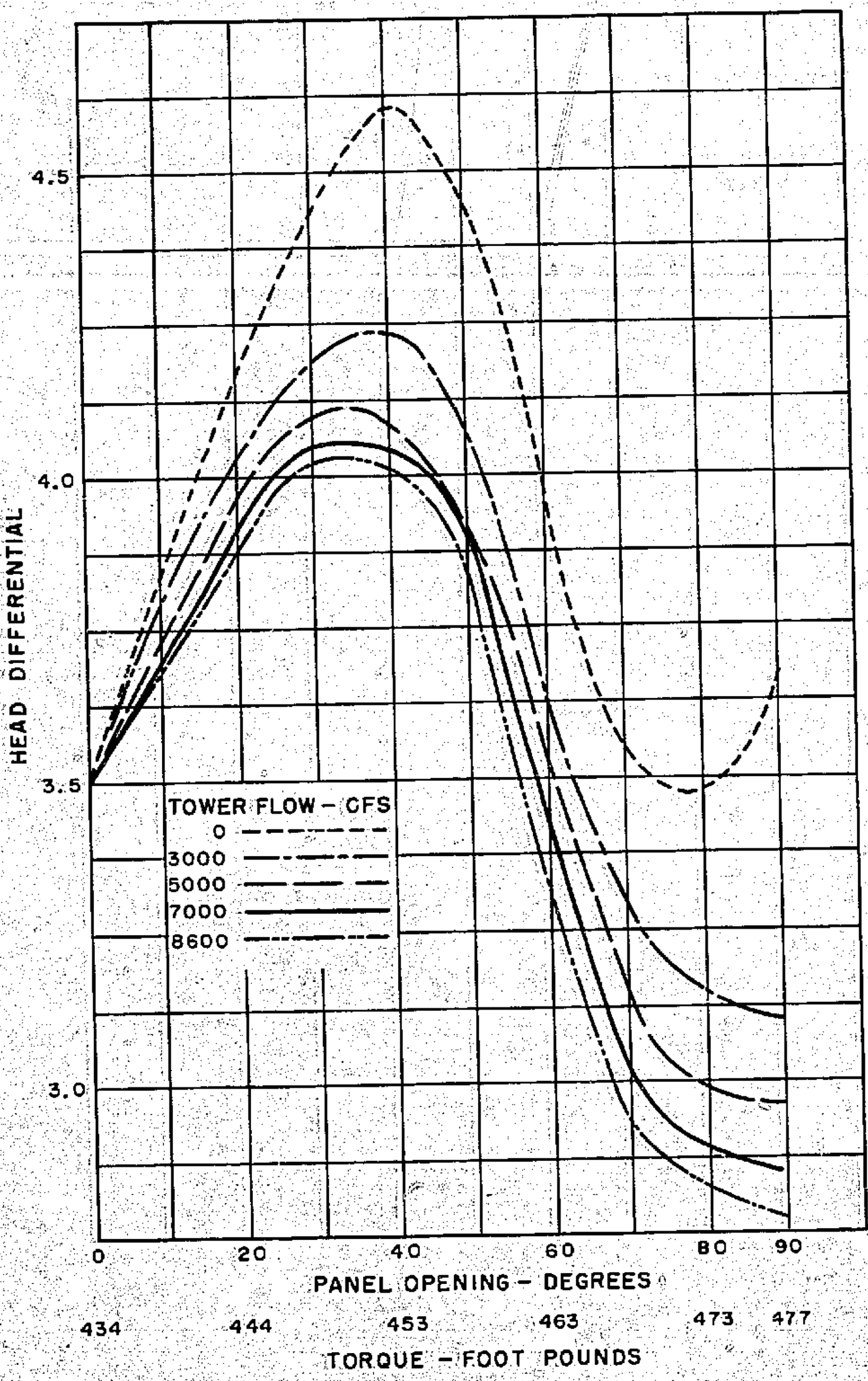


OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
1:4 SCALE MODEL
Operating differential head values
Entrance No. 3, panel No. 7
(Recommended)

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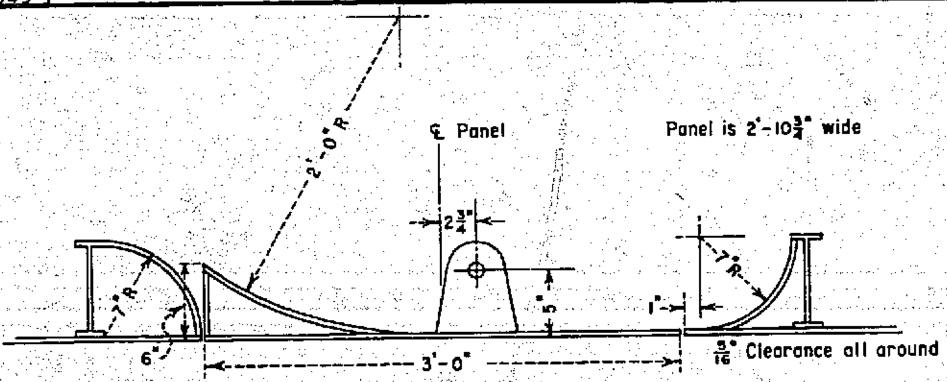
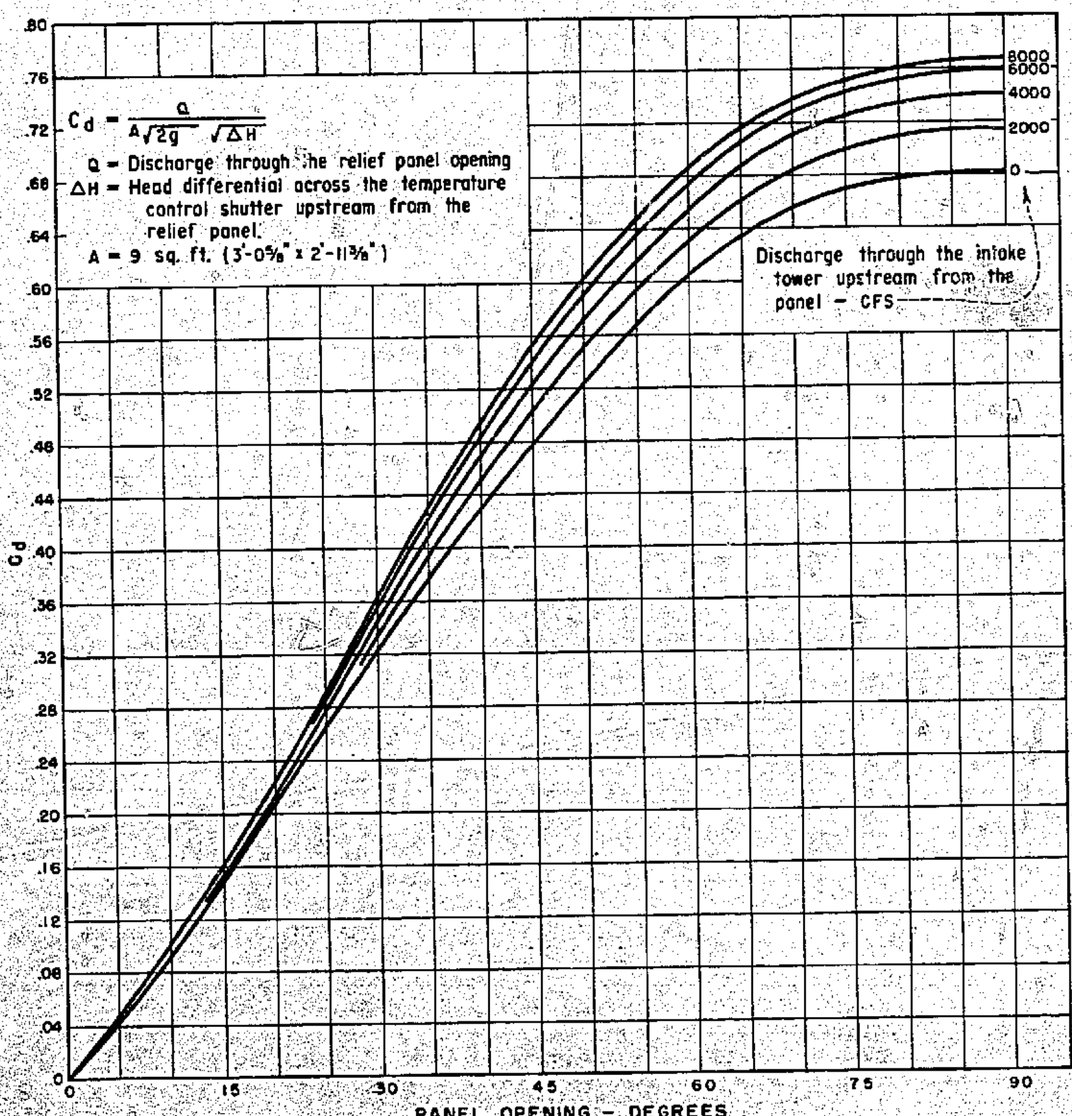



ENTRANCE SHAPE — TEST 3
PANEL SHAPE — TEST 7
(Recommended)




OROVILLE DAM
INTAKE STRUCTURES
PRESSURE RELIEF PANELS
1:4 SCALE MODEL
Discharge coefficient with and without flow through the intake tower.

7-1750
(10-64)

## CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

### Table 1

QUANTITIES AND UNITS OF SPACE

| Multiply | By | To obtain |
|---|---|---|
| | **LENGTH** | |
| Mil | 25.4 (exactly) | Micron |
| Inches | 25.4 (exactly) | Millimeters |
| | 2.54 (exactly)* | Centimeters |
| Feet | 30.48 (exactly) | Centimeters |
| | 0.3048 (exactly)* | Meters |
| | 0.0003048 (exactly)* | Kilometers |
| Yards | 0.9144 (exactly) | Meters |
| Miles (statute) | 1,609.344 (exactly)* | Meters |
| | 1.609344 (exactly) | Kilometers |
| | **AREA** | |
| Square inches | 6.4516 (exactly) | Square centimeters |
| Square feet | 929.03 (exactly)* | Square centimeters |
| | 0.092903 (exactly) | Square meters |
| Square yards | 0.836127 | Square meters |
| Acres | 0.40469* | Hectares |
| | 4,046.9* | Square meters |
| | 0.0040469* | Square kilometers |
| Square miles | 2.58999 | Square kilometers |
| | **VOLUME** | |
| Cubic inches | 16.3871 | Cubic centimeters |
| Cubic feet | 0.0283168 | Cubic meters |
| Cubic yards | 0.764555 | Cubic meters |
| | **CAPACITY** | |
| Fluid ounces (U.S.) | 29.5737 | Cubic centimeters |
| | 29.5729 | Milliliters |
| Liquid pints (U.S.) | 0.473179 | Cubic decimeters |
| | 0.473166 | Liters |
| Quarts (U.S.) | 9,463.58 | Cubic centimeters |
| | 0.946358 | Liters |
| Gallons (U.S.) | 3,785.43* | Cubic centimeters |
| | 3.78543 | Cubic decimeters |
| | 3.78533 | Liters |
| | 0.00378543* | Cubic meters |
| Gallons (U.K.) | 4.54609 | Cubic decimeters |
| | 4.54596 | Liters |
| Cubic feet | 28.3160 | Liters |
| Cubic yards | 764.55* | Liters |
| Acre-feet | 1,233.5* | Cubic meters |
| | 1,233,500* | Liters |

## Table II

### QUANTITIES AND UNITS OF MECHANICS

| Multiply | By | To obtain |
|---|---|---|
| **MASS** | | |
| Grains (1/7,000 lb) | 64.79891 (exactly) | Milligrams |
| Troy ounces (480 grains) | 31.1035 | Grams |
| Ounces (avdp) | 28.3495 | Grams |
| Pounds (avdp) | 0.45359237 (exactly) | Kilograms |
| Short tons (2,000 lb) | 907.185 | Kilograms |
| | 0.907185 | Metric tons |
| Long tons (2,240 lb) | 1,016.05 | Kilograms |
| **FORCE/AREA** | | |
| Pounds per square inch | 0.070307 | Kilograms per square centimeter |
| | 0.689476 | Newtons per square centimeter |
| Pounds per square foot | 4.88243 | Kilograms per square meter |
| | 47.8803 | Newtons per square meter |
| **MASS/VOLUME (DENSITY)** | | |
| Ounces per cubic inch | 1.72999 | Grams per cubic centimeter |
| Pounds per cubic foot | 16.0185 | Kilograms per cubic meter |
| | 0.0160185 | Grams per cubic centimeter |
| Tons (long) per cubic yard | 1.32894 | Grams per cubic centimeter |
| **MASS/CAPACITY** | | |
| Ounces per gallon (U.S.) | 7.4893 | Grams per liter |
| Ounces per gallon (U.K.) | 6.2362 | Grams per liter |
| Pounds per gallon (U.S.) | 119.829 | Grams per liter |
| Pounds per gallon (U.K.) | 99.779 | Grams per liter |
| **BENDING MOMENT OR TORQUE** | | |
| Inch-pounds | 0.011521 | Meter-kilograms |
| | $1.12985 \times 10^6$ | Centimeter-dynes |
| Foot-pounds | 0.138255 | Meter-kilograms |
| | $1.35582 \times 10^7$ | Centimeter-dynes |
| Foot-pounds per inch | 5.4431 | Centimeter-kilograms per centimeter |
| Ounce-inches | 72.008 | Gram-centimeters |
| **VELOCITY** | | |
| Feet per second | 30.48 (exactly) | Centimeters per second |
| | 0.3048 (exactly)* | Meters per second |
| Feet per year | $0.965873 \times 10^{-6}$* | Centimeters per second |
| Miles per hour | 1.609344 (exactly) | Kilometers per hour |
| | 0.44704 (exactly) | Meters per second |
| **ACCELERATION*** | | |
| Feet per second$^2$ | 0.3048* | Meters per second$^2$ |
| **FLOW** | | |
| Cubic feet per second (second-feet) | 0.028317* | Cubic meters per second |
| Cubic feet per minute | 0.4719 | Liters per second |
| Gallons (U.S.) per minute | 0.06309 | Liters per second |
| **FORCE*** | | |
| Pounds | 0.453592* | Kilograms |
| | 4.4482* | Newtons |
| | $4.4482 \times 10^{-5}$* | Dynes |
| **WORK AND ENERGY*** | | |
| British thermal units (Btu) | 0.252* | Kilogram calories |
| | 1,055.06 | Joules |
| Btu per pound | 2.326 (exactly) | Joules per gram |
| Foot-pounds | 1.35582* | Joules |
| **POWER** | | |
| Horsepower | 745.700 | Watts |
| Btu per hour | 0.293071 | Watts |
| Foot-pounds per second | 1.35582 | Watts |
| **HEAT TRANSFER** | | |
| Btu in./hr ft$^2$ deg F (k, thermal conductivity) | 1.442 | Milliwatts/cm deg C |
| | 0.1240 | Kg cal/hr m deg C |
| Btu ft/hr ft$^2$ deg F | 1.4880* | Kg cal m/hr m$^2$ deg C |
| Btu/hr ft$^2$ deg F (C, thermal conductance) | 0.568 | Milliwatts/cm$^2$ deg C |
| | 4.882 | Kg cal/hr m$^2$ deg C |
| Deg F hr ft$^2$/Btu (R, thermal resistance) | 1.761 | Deg C cm$^2$/milliwatt |
| Btu/lb deg F (c, heat capacity) | 4.1868 | J/g deg C |
| Btu/lb deg F | 1.000* | Cal/gram deg C |
| Ft$^2$/hr (thermal diffusivity) | 0.2581 | Cm$^2$/sec |
| | 0.09290* | M$^2$/hr |
| **WATER VAPOR TRANSMISSION** | | |
| Grains/hr ft$^2$ (water vapor transmission) | 16.7 | Grams/24 hr m$^2$ |
| Perms (permeance) | 0.659 | Metric perms |
| Perm-inches (permeability) | 1.67 | Metric perm-centimeters |

## Table III

### OTHER QUANTITIES AND UNITS

| Multiply | By | To obtain |
|---|---|---|
| Cubic feet per square foot per day (seepage) | 304.8* | Liters per square meter per day |
| Pound-seconds per square foot (viscosity) | 4.8824* | Kilogram second per square meter |
| Square feet per second (viscosity) | 0.02903* (exactly) | Square meters per second |
| Fahrenheit degrees (change)* | 5/9 exactly | Celsius or Kelvin degrees (change)* |
| Volts per mil | 0.03937 | Kilovolts per millimeter |
| Lumens per square foot (foot-candles) | 10.764 | Lumens per square meter |
| Ohm-circular mils per foot | 0.001662 | Ohm-square millimeters per meter |
| Millicuries per cubic foot | 35.3147* | Millicuries per cubic meter |
| Milliamps per square foot | 10.7639* | Milliamps per square meter |
| Gallons per square yard | 4.527219* | Liters per square meter |
| Pounds per inch | 0.17858* | Kilograms per centimeter |

## ABSTRACT

As a result of hydraulic model studies the relief panel and port recommended for the intake structures to prevent overpressures and structural damage to the temperature control shutters will open and close satisfactorily within the differential head range specified. Water for the left powerplant will flow through 2 parallel inclined 650-ft-long intake structures. A train of 13 temperature control shutters will be installed in each tower to form a roof. Shutters may be removed one at a time, starting with the uppermost, to release reservoir waters of desired temperature downstream. The studies were undertaken because inadvertent occurrences or an operational procedure might cause instantaneous head differentials in excess of the allowable maximum of 5 ft of water between the upper and lower side of the shutters. To prevent overpressures, relief panels will be installed in the lower temperature control shutters of each tower. The panels will be held closed by a torsion spring and will start to open at a 3.5-ft head differential and swing fully opened at a 4.6-ft differential. They will close at differentials less than 2.77 ft. Ninety-four panels will pass the maximum 8,600-cfs power demand in one tower with a 3.5-ft head differential across the shutters. The port with a convex rounding at the panel dropping edge and concave at the rising edge was selected as the best entrance configuration because it produced the highest torque at midrange.



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